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Short Communication

Upper limb movement analysis during gait in multiple sclerosis patients

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ABSTRACT

Purpose: Gait disorders in multiple sclerosis (MS) are well studied; however, no previous study has described upper limb movements during gait. However, upper limb movements have an important role during locomotion and can be altered in MS patients due to direct MS lesions or mechanisms of compensation. The aim of this study was to describe the arm movements during gait in a population of MS patients with low disability compared with a healthy control group.
Methods: In this observational study we analyzed the arm movements during gait in 52 outpatients (mean age: 39.7 ± 9.6 years, female: 40%) with relapsing-remitting MS with low disability (mean EDSS: 2 ± 1) and 25 healthy age-matched controls using a 3-dimension gait analysis.
Results: MS patients walked slower, with increased mean elbow flexion and decreased amplitude of elbow flexion (ROM) compared to the control group, whereas shoulder and hand movements were similar to controls. These differences were not explained by age or disability.
Conclusion: Upper limb alterations in movement during gait in MS patients with low disability can be characterized by an increase in mean elbow flexion and a decrease in amplitude (ROM) for elbow flexion/extension. This upper limb movement pattern should be considered as a new component of gait disorders in MS and may reflect subtle motor deficits or the use of compensatory mechanisms.

1. Introduction

In multiple sclerosis (MS), motor deficits most commonly affect the lower extremities and gait abnormalities represent a major feature of the disease (Benedetti et al., 1999). Individuals with MS walk slower, take shorter, wider and slower steps, and spend greater percent of the gait cycle in double support (Allali et al., 2012; Givon, Zeilig, & Achiron, 2009; Kelleher et al., 2010; Sosnoff, Sandroff, & Motl, 2012). Although gait disorders in MS are well described, no studies have studied upper limb movements using 3D motion analysis despite the important role of arms movements in gait (Meyns, Bruijn, & Duysens, 2013).

Many studies have reported the role of arm movements during both healthy and pathological gait (Eke-Okoro, Gregoric, & Larsson, 1997; Ford, Wagenaar, & Newall, 2007; Meyns et al., 2013). Arm swing during human locomotion reduces

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the energetic cost of walking and facilitates leg movements (Meyns et al., 2013). This may be due to a greater angular momentum about the vertical that needs to be counteracted (Collins, Adamczyk, & Kuo, 2009) or because of the larger vertical movements of the center of mass that occur when the arms do not swing upward when the trunk moves downward (Umberger, 2008). In addition to this, many authors have claimed that arm swing during gait improves stability (Bruijn et al., 2010). In neurological conditions, such as Parkinson's disease (PD), altered arm swing movement and asymmetry during gait is often reported (Lewek et al., 2010), and rehabilitation of arm swing has been recognized to improve gait and normalize arm swing in patients with PD (Yoon et al., 2016). However, arm swing movement and asymmetry have been not studied in MS.

MS patients, even with low levels of disability (Morel et al., 2017), present with gait deviations. Therefore, arm movements in MS patients may be altered for two reasons, firstly, as a direct consequence of MS lesions, such as demyelinating lesions in the spinal cord, brain or cerebellum, and secondly as a compensatory mechanism resulting from lower-limbs gait deviations. Therefore, we hypothesize that MS patients would present abnormal upper limbs movements, even in the very mild form of the disease, in comparison to healthy adults. This study aims to compare upper limb movements during gait in MS patients with a control group and to study their association with age, disability and gait velocity.

2. Methods

2.1. Participants

Fifty-two outpatients with relapsing – remitting MS from the Department of Neurology at the Geneva University Hospitals and 25 healthy controls were included. The study protocol has been previously described in detail (Allali et al., 2014). Briefly, exclusion criteria were: acute medical illness in the past month, neurological and psychiatric diseases except MS, and any concomitant orthopaedic, rheumatologic or vestibular conditions that affect walking. All patients were stable without any MS exacerbation within 60 days prior to participation. The research protocol was approved by the Geneva University Hospitals Committee on Human research, and informed consent was obtained from all participants.

2.2. Upper limb movements

Shoulder angles in the frontal plane and elbow angles in the sagittal plane during walking were analyzed individually for the MS and control participants.

The shoulder angle corresponded to the abduction-adduction angle, which was defined as the motion of the humerus relative to the thorax in the frontal plane (Bonnefoy-Mazure et al., 2010). A positive angle corresponded to abduction (i.e., the humerus moving away from thorax). The elbow angle corresponded to the flexion/extension angle, a positive angle reflected a flexion movement, and a negative angle an extension movement. The normalized (by the patient's height) position of the hand was computed along the x-axis (anterior-posterior direction) and z-axis (top-bottom direction) to determine respectively a guard position of the hand and the elevated hand position. Finally, the arm angle was calculated as the angle between the upper arm segment and vertical axis (to measure the degree of the swinging motion in the arm) in the sagittal plane (Bonnefoy-Mazure et al., 2014; Meyns et al., 2011).

For the shoulder angle, the elbow angle, the hand movements and arm angles, two discrete parameters were computed during the gait cycle: the range of motion (ROM) value and the mean value. Arm swing was also described using an asymmetry index: the arm swing asymmetry was designed to represent asymmetry in arm swing magnitude between each arm and was calculated using a method previously validated by Zifchock et al. Zifchock et al. (2008).

2.3. Gait analysis

The gait analysis protocol was previously described in detail (Allali et al., 2012, 2014). Briefly, the participants' gait was recorded with a twelve-camera motion analysis system (VICON Mx3+; ViconPeak®, Oxford, UK) at self-selected gait speed along a 12-meter walkway. Data were collected for at least 3 gait cycles for each individual.

2.4. Statistics

The MS and control groups were compared with each other for all biomechanical parameters used to characterize the gait and the upper limb movements using an independent samples T test, the statistical significance was $p < 0.05$. The effects of age, EDSS (Expanded Disability Status Scale) and gait speed (independent variables) on upper limbs movements (dependent variable) were investigated with multivariable linear regression analysis. The comparisons were performed using SPSS (v.22, IBM Statistics, USA).

3. Results

3.1. Upper limb movements

As seen in Table 1, MS patients had a reduced elbow flexion ROM ($p = 0.006$) and an increase mean flexed elbow position ($p = 0.003$). In addition, the mean arm angle was significantly higher in the MS group ($p = 0.001$). However, neither the hand nor the shoulder kinematics showed any significant difference between the groups.

Table 1
Mean (and standard deviation) values of the kinematic parameters of the arms and temporal-spatial gait parameters in multiple sclerosis (MS) patients and control group.

	MS (n = 52)	Controls (n = 25)	p-Value
Age (years)	39.7 (9.6)	35.5 (8.6)	0.061
Height (m)	1.6 (8.36)	1.6 (8.5)	0.641
BMI ($kg.m^{-2}$)	24.5 (4.35)	22.1 (2.1)	**0.041**
EDSS	2 (1)	NA	NA
Sex (M:F)	21 : 31	6: 19	0.162
Gait			
Normalized Speed ($m.s^{-1}$)	1.3 (0.4)	1.4 (0.3)	**0.018**
Cadence (steps/min)	119.4 (18.6)	119.5 (17.2)	0.302
Stance (% GC)	62.3 (3.6)	59.8 (1.5)	**0.006**
Stride Length (m)	1.0 (0.2)	1.2 (0.2)	**0.012**
Shoulder (°)			
Shoulder ROM	14.6 (5.2)	15.9 (4.9)	0.479
Shoulder Mean	28.3 (5.1)	27.1 (5.3)	0.146
Elbow (°)			
Elbow ROM	27.6 (10.3)	32.1 (9.8)	**0.006**
Elbow Mean	36.4 (6.7)	33.8 (4.2)	**0.003**
Hand (% body size)			
Hand AnteroPost ROM	0.2 (0.06)	0.25 (0.1)	0.087
Hand AnteroPost Mean	0.0 (0.04)	−0.01 (0.0)	0.051
Hand Vertical ROM	0.07 (0.03)	0.08 (0.0)	0.254
Hand Vertical Mean	−0.1 (0.02)	−0.1 (0.0)	0.821
Arm (°)			
Arm Angle ROM	8.3 (3.1)	8.2 (3.1)	0.866
Arm Angle Mean	21.4 (4.1)	19.2 (3.6)	**0.001**
Asymmetry (%)			
Arm swing	7.2 (7.1)	9.4 (7.1)	0.185

Abbreviations: IC, Initial Contact; ROM, Range of Motion; Max, Maximum, Min, Minimum, AnteroPost, Anterior-Posterior, and GC, Gait Cycle. Mean (SD). Significant statistical correlations in bold ($p < 0.05$).

3.2. Gait

MS patients walked significantly slower than the control group ($p = 0.018$) with a longer stance phase ($p = 0.006$) and a shorter stride length ($p = 0.012$).

3.3. Asymmetery

Table 1 shows that no significant difference was seen in arm asymmetry between MS patients and the control group.

3.4. Regression analysis

Using a multivariable linear regression, normalized gait speed was found to be associated with elbow flexion ROM ($\beta = 0.55$, $p < 0.01$), however neither EDSS score nor age predicted elbow flexion ROM. Mean arm and elbow angles were not predicted by age, EDSS or normalized gait speed.

4. Discussion

MS patients with low disability moved their arms with a significantly decreased elbow flexion in term of ROM and an increased average elbow flexion during the gait cycle; and with significant higher average movement of the arm angle in the sagittal plane. However, MS patients had similar shoulder and hand movements compared to the control group. In addition, this sample of patients with a low level of disability did not show any asymmetric features in arm movement in comparison with healthy adults.

The findings presented in this study indicate that even at this early stage of the disease, patients with MS demonstrate abnormal arm movements affecting specifically their elbow in comparison to healthy adults. At this early stage of the disease, patients do not appear to need to use shoulder abduction to equilibrate their gait and to maintain their postural stability.

These alterations in arm position and movement may result from demyelinating lesions that accumulate in the brain and spinal cord throughout the course of the disease. Demylinating lesions such as those found in MS patients may be responsible for these subtle motor deficits. Previous studies have reported the effect demyelinating lesions have on gait, posture and global motor function in MS patients (Bjartmar & Trapp, 2001; Ruggieri, Castelli, Petsas, De Giglio, & Prosperini, 2017).

These findings may also be a result of compensatory strategies employed to improve gait speed, pattern, stability and balance during gait. Among the most common symptoms of MS are motor impairments such as deficits in gait and balance (Motl et al., 2008). Approximately 85% of individuals with MS report walking dysfunction to be a major impairment in their daily lives (Lobentanz et al., 2004). Balance dysfunction is also regularly reported by individuals with MS even in individuals with a low level of disability (Martin et al., 2006) (Wadja & Sosnoff, 2015). Abmormal arm swing movements have been previously reported in patients with Parkinson's Disease (Huang et al., 2012; Lewek et al., 2010), and these abnormalities have been found to result from compensatory mechanisms employed to aid in their gait.

This study confirms that MS patients with low disability walk slower, have a longer stance phase and a shorter stride length than the control group (Comber, Galvin, & Coote, 2017). Furthermore, our findings are in line with the observation that disturbed arm movements can influence gait patterns, however it is not clear if disturbed arm movements are compensatory mechanism employed to counteract disturbed gait (4) or are a direct consequence of MS impairments (Benedetti et al., 1999). Previous studies have described a relationship between arm swing and gait speed (Bruijn et al., 2010; Eke-Okoro et al., 1997), which may explain further the association between gait speed and elbow flexion ROM.

This study has several limitations. As we focused on MS patients with low disability, our findings cannot be generalized for patients with higher EDSS. MS patients in this study also had a significantly higher BMI than controls, this is something that may have affected arm swing and warrants further investigation in future work. Furthermore, in a future study, it would be of interest to examine the prognostic value of upper limb movements in MS patients using a longitudinal approach. This may enable the use of upper limb movements as a biomarker of disease progression.

In addition, this study has not discussed interlimb coordination or measures of coupling which have never been investigated in the MS population. This article has focused on upper-limb movement during gait without considering lower-limb movements or deviations. However in future work it would be pertinent to further investigate the link between lower limbs and upper limbs deviations during gait.

Finally, further investigation is warranted to clarify the cause/origin of the altered arm movements observed in this study.

5. Conclusions

Upper limb alterations during gait in MS patients with low disability can be characterized by an increase in mean elbow flexion and a decrease in amplitude (ROM) for elbow flexion/extension. This description of abnormal upper limb movement during gait in individuals with MS may reflect the signature of subtle motor deficits or the use of compensatory mechanisms and could be considered as a new component of gait disorders in MS.

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Declaration of interest

The authors report no declarations of interest.

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References

Allali, G., et al. (2012). Adapted timed up and go: a rapid clinical test to assess gait and cognition in multiple sclerosis. *European Neurology*, *67*(2), 116–120.
Allali, G., et al. (2014). Walking while talking in patients with multiple sclerosis: the impact of specific cognitive loads. *Neurophysiologie Clinique*, *44*(1), 87–93.
Allali, G., et al. (2014). Dual-task assessment in natalizumab-treated multiple sclerosis patients. *European Neurology*, *71*(5–6), 247–251.
Benedetti, M. G., et al. (1999). Gait abnormalities in minimally impaired multiple sclerosis patients. *Multiple Sclerosis*, *5*(5), 363–368.
Bjartmar, C., & Trapp, B. D. (2001). Axonal and neuronal degeneration in multiple sclerosis: mechanisms and functional consequences. *Current Opinion in Neurology*, *14*(3), 271–278.
Bonnefoy-Mazure, A., et al. (2010). Rotation sequence is an important factor in shoulder kinematics. Application to the elite players' flat serves. *Journal of Biomechanics*, *43*(10), 2022–2025.
Bonnefoy-Mazure, A., et al. (2014). A descriptive analysis of the upper limb patterns during gait in individuals with cerebral palsy. *Research in Developmental Disabilities*, *35*(11), 2756–2765.
Bruijn, S. M., et al. (2010). The effects of arm swing on human gait stability. *Journal of Experimental Biology*, *213*(Pt 23), 3945–3952.
Collins, S. H., Adamczyk, P. G., & Kuo, A. D. (2009). Dynamic arm swinging in human walking. *Proceedings of the Royal Society B: Biological Sciences*, *276*(1673), 3679–3688.
Comber, L., Galvin, R., & Coote, S. (2017). Gait deficits in people with multiple sclerosis: A systematic review and meta-analysis. *Gait Posture*, *51*, 25–35.
Eke-Okoro, S. T., Gregoric, M., & Larsson, L. E. (1997). Alterations in gait resulting from deliberate changes of arm-swing amplitude and phase. *Clin Biomech (Bristol, Avon)*, *12*(7–8), 516–521.
Ford, M., Wagenaar, R., & Newall, K. (2007). Arm constraint and walking in healthy adults. *Gait & Posture*, *26*, 135–141.
Givon, U., Zeilig, G., & Achiron, A. (2009). Gait analysis in multiple sclerosis: characterization of temporal-spatial parameters using GAITRite functional ambulation

system. *Gait Posture*, *29*(1), 138–142.
Huang, X., Mahoney, M. J., Lewis, M. M., Du, Guangwei, Piazza, S. J., & Cusumano, J. P. (2012). Both coordination and symmetry of arm swing are reduced in Parkinson's disease. *Gait & Posture*, *35*(3), 373–377.
Kelleher, K. J., et al. (2010). The characterisation of gait patterns of people with multiple sclerosis. *Disability and Rehabilitation*, *32*(15), 1242–1250.
Lewek, M. D., et al. (2010). Arm swing magnitude and asymmetry during gait in the early stages of Parkinson's disease. *Gait Posture*, *31*(2), 256–260.
Lobentanz, I. S., et al. (2004). Factors influencing quality of life in multiple sclerosis patients: disability, depressive mood, fatigue and sleep quality. *Acta Neurologica Scandinavica*, *110*(1), 6–13.
Martin, C. L., et al. (2006). Gait and balance impairment in early multiple sclerosis in the absence of clinical disability. *Multiple Sclerosis*, *12*(5), 620–628.
Meyns, P., et al. (2011). Arm swing during walking at different speeds in children with Cerebral Palsy and typically developing children. *Research in Developmental Disabilities*, *32*(5), 1957–1964.
Meyns, P., Bruijn, S. M., & Duysens, J. (2013). The how and why of arm swing during human walking. *Gait Posture*, *38*(4), 555–562.
Morel, E., et al. (2017). Gait Profile Score in multiple sclerosis patients with low disability. *Gait Posture*, *51*, 169–173.
Motl, R. W., et al. (2008). Worsening of symptoms is associated with lower physical activity levels in individuals with multiple sclerosis. *Multiple Sclerosis*, *14*(1), 140–142.
Ruggieri, S., Fanelli, F., Castelli, L., Petsas, N., De Giglio, L., & Prosperini, L. (2017). Lesion symptom map of cognitive-postural interference in multiple sclerosis. *Multiple Sclerosis*.
Sosnoff, J. J., Sandroff, B. M., & Motl, R. W. (2012). Quantifying gait abnormalities in persons with multiple sclerosis with minimal disability. *Gait Posture*, *36*(1), 154–156.
Umberger, B. R. (2008). Effects of suppressing arm swing on kinematics, kinetics, and energetics of human walking. *Journal of Biomechanics*, *41*(11), 2575–2580.
Wadja, D., & Sosnoff, J. (2015). Cognitive-motor interference in multiple sclerosis: A systematic review of evidence, correlates, and consequences. *BioMed Research International*, *2015*, 8.
Yoon, J., et al. (2016). The effects of additional arm weights on arm-swing magnitude and gait patterns in Parkinson's disease. *Clinical Neurophysiology*, *127*(1), 693–697.
Zifchock, R. A., et al. (2008). The symmetry angle: a novel, robust method of quantifying asymmetry. *Gait Posture*, *27*(4), 622–627.